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Supplementary material:

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MATERIALS AND METHODS

The experiment in this work was preformed at the Titan laser facility (S1) where a short pulse beam at a wavelength of 1053nm delivered up to 350J in 0.5 to 20 ps and a long pulse beam at 527nm, 2ω frequency provided energies up to 450J in 1 to 6 ns. Long pulse shaping in this experiment, similar to future capabilities at NIF, was primarily a 4ns long foot with an intensity of $1x10^{13}$ W/cm^2, followed by a 2ns long peak with an intensity of $3x10^{13}$ W/cm^2. A ~ 600 um phase plate was used on the long pulse beam to moderate non-uniformities in the intensity profile. An illustration of the Thomson scattering setup for this experiment is provided in Fig. 1 of the main text.

A nearly mono-energetic scattering source of $\Delta E/E \sim 0.3\%$ in the 4.5 keV Ti K-alpha line was produced via intense short-pulse laser irradiation of 1.9x3x0.01 mm Ti foils, creating energetic keV electrons in the process (S2, S3). The nearly isotropic source emission (S4) is produced in the cold solid density bulk of the foil from electron K shell ionization of neutral or weakly ionized atoms, with an emission size on the order of the laser focal spot. By optimizing the laser intensity and pulse width to $4.4x10^{16}$ W cm^{-2}, a total of $2.3x10^{13}$ x-ray photons have been produced into 4π. This value corresponds to a conversion efficiency of laser energy into Ti K-alpha x-ray energy of $5x10^{-5}$, see Fig. S1. These sources provide ~10 ps x-ray pulses as measured experimentally (S5).

Lithium Hydride (LiH) targets (ρ_O=0.78g/cc) were probed with the Ti K-α sources that were Thomson scattered from long-pulse laser compressed 1.9x3x0.3 mm LiH targets. The targets were mounted on a Photo-structurable glass holder along with the Ti source foil and three 10x7.5x0.025 mm gold shields to block the source and blow-off plasmas to the scattering spectrometer. The glass holder restricted the view of the source x rays to the target, yielding a solid angle of $1.6x10^{-1}$ sr. The measured transmission of 0.53% through 300 μm, respectively, restricted scattered photons seen by the spectrometer to a volume of approximately 0.1x0.4x0.3 mm. The low transmission of the LiH targets compared to a predicted value of ~ 96% through 300μm (S6) is attributed to impurities (<2%) in the sample and a thin oxide layer of <20 μm. In this case, of the $2.3x10^{13}$ photons produced it was predicted that 2.9×10^{11} would reach the scattering target and 8.5×10^{8} photons would scatter elastically.

To collect the scattered radiation, Highly Oriented Pyrolitic Graphite crystal spectrometers (HOPG) oriented in a VanHamos geometry that employed a curved crystal to focus the radiation were used. Here mosaic focusing was achieved by setting the source-to-crystal and crystal-to-detector distances to the focal distance, $F=R/\sin(\theta_B)$, where R is the crystal radius of curvature and θ_B is the Bragg scattering angle. For conditions in this experiment, i.e. second order crystal alignment and R= 11.5 cm, the focal distance was approximately 13.1 cm. A free standing HOPG crystal was used to decrease potential florescence of materials in proximity of the crystal. The solid angle of the 70 x 24 mm scattering spectrometer crystal was 1.6×10^{-3} sr, with a view of 534 mrad in the non-dispersive plane and 3 mrad in the dispersive plane due to the mosaicity of the crystal. To detect the scattered radiation, BAS-TR type image plates with high resolution were used. In the spectral direction, one pixel (25 μm) corresponded to 0.33eV. Noise and background from bremsstrahlung radiation was filtered out using a 0.025 mm thick Be foil placed in front of the image plate detector. From the 8.5×10^{8} scattered photons, it was predicted that $\sim1\times10^{5}$ would be collected by the HOPG spectrometers, corresponding to $\sim1\times10^{6}$ counts on the image plate detectors. This agrees with experimental data for scattering from uncompressed LiH targets.

Figures S2 shows the density sensitivity of theoretical fits (S7) to the experimental scattering data at 7ns after the launch of the first shock into the LiH target. Here, the intensity of the plasmon scattering feature and the plasmon shift increase with increasing density indicating that the density is accurately inferred from the data. With knowledge of the density from the plasmon spectrum, the temperature has then been inferred from the intensity of the elastic scattering signal.

Figure S3 shows the Root Mean Squared (RMS) values of the experimental data compared to theoretical spectra calculated for a range of temperatures and electron densities. The black-colored island in the center of the plot indicates best theoretical fits with about 10% and 15% error in the temperature and electron density, respectively. Therefore, determining the correct fit to the experimental data can be achieved with high accuracy.

OTHER RELEVANT WORK

Recent proof of principal spectrally resolved x-ray scattering experiments have provided a basis for x-ray Thomson scattering from solid density plasmas. In these experiments, scattering in the collective and non-collective regimes with He-alpha or Ly-alpha sources have revealed experimental constraints and requirements for successful scattering. Here, densities, temperatures, and ionization states of warm dense matter have been obtained, enabling, e.g., the measurements of the optical properties of dense matter (S8, S9, S10). These experiments have compelled the need to refine scattering codes in this regime where the calculation of structure factors, collisions, and screening models are controversial (S7). In this work, the first experimental x-ray scattering data from shock compressed targets have shown the direct measurement of thermodynamic properties.

SUPPORTING REFERENCES AND NOTES

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SUPPORTING FIGURES

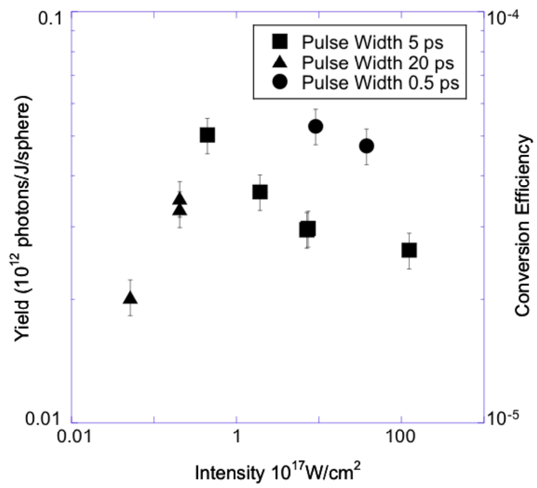

Fig. S1: Conversion efficiency of Laser energy into Ti K-alpha radiation as a function of varying short-pulse laser intensity. Conversion efficiencies for a pulse width of 0.5 ps were greater than for 5 ps, but the ladder was used due to restrictions on available laser energy for a 0.5 ps pulse. The observed increase in conversion efficiency with decreasing laser intensity was observed previously (S3).

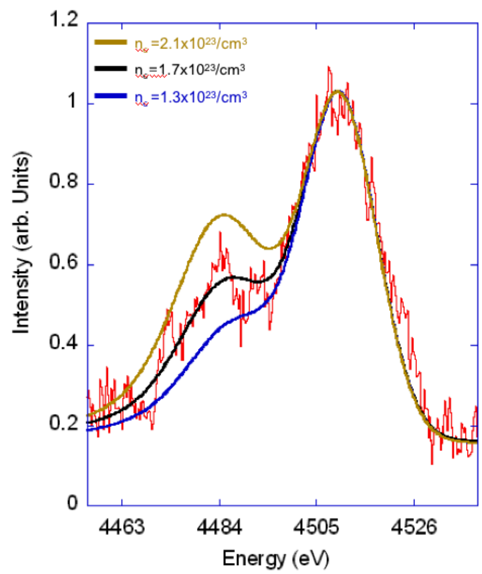

Fig. S2: Experimental scattering of Ti K-alpha from compressed LiH, 7ns after the first of two shocks was launched into the solid density target with fitted profiles. Sensitivity of density changes in the theoretical fit to the experimental data is shown above with the best fit (black) at 1.7 x10^{23}/cm^{3}, compared to fits with 1.7 $\pm$ 0.4 x10^{23}/cm^{3} (blue and tan curves). Here, the temperature and ionization state, 2.2 eV and Zf=1, respectively, are held constant.

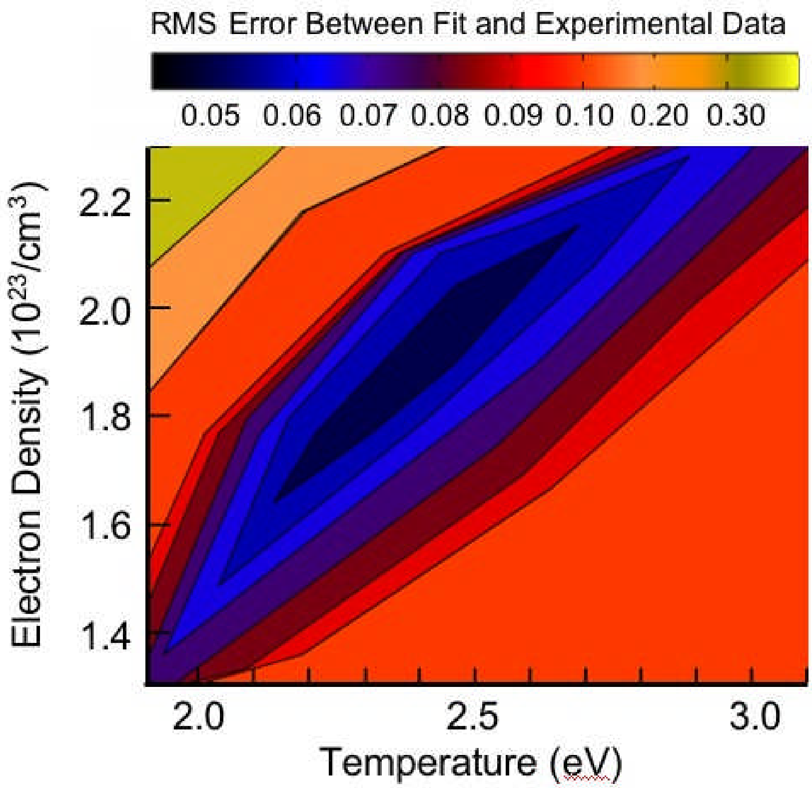

Fig. S1: Sensitivity of OCP fitting to the experimental spectra for varying temperatures and electron densities. Root Mean Squared (RMS) values are color coded for given temperature and density combinations, where the centered black island is a range of possible best fits. The error of this fitting method to the experimental data is about ± 10% for temperature and ± 15% for electron density.